Sampling and Reconstruction of Visual Appearance

CSE 274 [Fall 2018], Lecture 5
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Applications: Sampling/Reconstruction
- Monte Carlo Rendering (biggest application)
- Light Transport Acquisition
- Light Fields and Computational Photography
- Animation/Simulation (not covered in course)

- Brief overview of these applications today, and opportunities/history for sampling/reconstruction

Motivation
- Distribution effects (depth of field, motion blur, global illumination, soft shadows) are slow. Many dimensions sample
- Ray Tracing physically accurate but slow, not real-time
- Can we adaptively sample and filter for fast, real-time?

Monte Carlo Path Tracing
- 1000 paths/pixel

Sampling and Reconstruction
- Monte Carlo is noisy at low sample counts
- Can we reduce time/samples by smart adaptive sampling and smart filtering/reconstruction?
- General area of Monte Carlo denoising
- Long history [Mitchell 91, Guo 98]

History
- Adaptive sampling old technique Mitchell et al. 87, 91,…
- But not very widely used… artifacts, can miss features
- After seminal papers in 87-91, not much follow on
Directional Coherence Maps

- Allocate samples to edges (Guo 98)
  - Most of variance at those edges in the image

Directional Coherence Maps (Guo 98)

Resurgence (2008 -)

- Eurographics 2015 STAR report by Zwicker et al. [former UCSD faculty]
  - Proposed use for adaptive sampling.
  - Not very practical

Multi-Dimensional Adaptive Sampling

- Hachisuka, Jarosz, … Zwicker, Jensen [MDAS 2008]
- Scenarios with motion blur, depth of field, soft shadows
- Involves high-dimensional integral, converges slowly
- Exploit high-dimensional info to sample adaptively
- Sampling in 2D image plane or other dims inadequate
  - Need to consider full joint high-dimensional space

Multi-Dimensional Adaptive Sampling

Figure 10: Visualizations of projected sample distributions using our method for the chess scene from Figure 8 and the pool scene from Figure 7. Our adaptive sampler places samples both around high-frequency image discontinuities (e.g., chess piece and stationary pool ball) as well as in regions which exhibit significant motion blur or depth of field effects.
Multi-Dimensional Adaptive Sampling

A-Priori Methods
- Egan et al. 2009: Frequency Analysis and Sheared Filtering for Motion Blur; first deep use frequency anal.

A-Posteriori Methods
- Adaptive Wavelet Rendering (Overbeck et al. 2009)
  - Handle general effects. Sample and denoise
  - Many more sophisticated methods available now; used in almost every major production rendering software
  - And at least one startup company

Real-Time
- Axis-Aligned Filtering (Mehta et al. 12,13,14)
- Optix plus image-space filtering
- Newer extensions to sheared filtering
- Most recent work (NVIDIA) is fully general. 1 sample per pixel, using modern machine learning methods (similar ideas relevant in offline rendering as well)
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Acquiring Reflectance Field of Human Face [Debevec et al. SIGGRAPH 00]
Illuminate subject from many incident directions

Example Images

Motivation: Image-based Relighting
Sample Lighting Directions

Motivation: Image-based Relighting
Sample Lighting Directions
Motivation: Image-based Relighting

Sample Lighting Directions

Relight

4096 Samples

+10000 Samples

Brute Force Capture Practically Impossible

Compressible / Sparseness

AI Coefficients

Ψ

Ψ

5% Largest Coeff.

Measurements

Canonical Domain

Wavelet Domain

Measured Quanta

Measurements

Canonical Domain

Wavelet Domain

Measured Quanta
Compressive Sensing: A Brief Introduction

- Sparsity / Compressibility:
  - Signals can be represented as a few non-zero coefficients in an appropriately-chosen basis, e.g., wavelet, gradient, PCA.

- For sparse signals, acquire measurements (condensed representations of the signals) with random projections.

\[ A_{m \times n} \begin{bmatrix} x \end{bmatrix} = b_{m \times 1} \]

**Resolution**

- 1000 Measurements
- 128 x 128 Lighting Resolution
- 128 Haar Wavelet Coefficients
Results

Reference
1000 Measurement
128 x 128 Lighting Resolution
128 Haar Wavelet Coefficients

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Light Field Rendering

Marc Levoy    Pat Hanrahan

Computer Science Department
Stanford University

Apple’s QuickTime VR

Outward
Inward
**Generating New Views**

Problem: fixed vantage point/center
One Solution: view interpolation
- Interpolating between range images (Chen and Willsky, 1999)
- Correspondences and epipolar analysis (McMillan and Bishop, 1995)
  > Requires depths or correspondences:
  must be extracted from acquired imagery
  relatively expensive and error-prone method

**Light Fields**

Gershun’s and Moon’s idea of a light field:
Radiance as a function of a ray or line: \( I(\vec{x}, y, z, \theta, \phi) \)
- In “free space” (no occluders) 5D reduces to 4D
- Exterior of the convex hull of an object
- Interior of an environment
- Images are 2D slices
  - Insert acquired imagery
  - Extract image from a given viewpoint

**4D Light Field**

A degree of freedom gantry
Lytro Camera

**Light Field as a 2D Array of Images**

Camera Array

\[ L(r) = L(u, v, s, t) \]
Light fields

Resolution trade-off

Solution: angular super-resolution

Compression Example
**Straightforward solution**
- Model the process with a single CNN

**High-level idea**
- Follow the pipeline of existing techniques and break the process into two components
  - Disparity estimator
  - Color predictor
- Model the components using learning
- Train both models simultaneously

**Single CNN’s result**

**Our result**

**Light field video**
- Consumer light field cameras limited bandwidth
- Capture low frame rate videos

**4D RGBD Light Fields from 2D Image**

**Light field video**
- Lytro illum (3 fps video)
Our result

Summary

- Brief overview of applications, some algorithms
- Will cover in greater detail in rest of course
- Biggest practical progress in Monte Carlo rendering: order of magnitude speedups
- Widely used in production, also in real-time
- Very relevant in light transport acquisition
- Sampling/Reconstruction key for light fields
- Many other applications: PRT, Animation, etc.